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Determination of operating parameters of industrial engine fuelled with post processing gases with high hydrogen content

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Abstract. The results of investigations of SI engine fuelled with hydrogen and mixed n-butanol with isobutanol have been presented in article. The idea of flexible feeding system and the aim and methodology of carried out measurement have been also described. Obtained results have been compared to the results of tests carried out during flexible feeding of the same engine. The proposed control system enables not only application of different liquid and gaseous fuels but also application of the fuels which chemical composition vary within the relatively short time intervals.

1. Introduction

An important objective of the scientific and economic, leading to the rationalization of the use of different energy sources is the exploration and use of new fuels for combustion engines. There is a large group of fuels which are not suitable for use in traction vehicles for various reasons. That group of fuels, however, can be used in power generation applications. To this group belong the various types of combustibles, which are the waste product of certain industrial processes. One such type of fuels is industrial hydrogen or gas mixture containing a large proportion thereof, as well as various types of alcoholic liquid phases. This type of waste fuels are typically used at most heating purposes, but they are often irretrievably lost by burning in a torch.

Their development for low-energy seems to be a reasonable solution, the more that this type of system allows for flexible adaptation of the type of energy to current needs. This corresponds to the modern trend towards diversification of energy sources. Suitably adapted, the internal combustion piston engine, working with a power generator, can be both, a heat source and a source of electricity.

2. Waste fuels from industrial processes

In the study conducted at the Institute of Automobiles and Internal Combustion Engines Cracow University of Technology the waste fuel from the chemical industry has been taken into account. That fuel was in the form of a gas containing a high concentration of hydrogen and liquid fuels, which are a mixture of alcohols. An example of such fuel is the so-called butanol loop waste gas of the consisting of: H_2 –85%, N_2 – (6-8)%, CH_4 – (2-4)%, O_2 – (1-2)%, CO_2 – (1-2)%, or so-called octanol loop waste gas consisting of: H_2 – 80%, N_2 – (8-10)%, CH_4 – (4-6)%, O_2 – (1-2)%, CO_2 – (1-2)%. The waste liquid phase is usually comprised mainly of a mixture of alcohols: n-butanol, isobutanol, propanol, and octanol. In the conducted laboratory studies substitute fuels were used to capture the physical and chemical characteristics of listed waste fuels. As a gas fuel, industrial hydrogen was used, and as liquid fuel, a mixture of 50% n-butanol and 50% isobutanol. For comparative purposes the high methane natural gas was used.

3. Object of research and measurements

As the object of study was selected 6-cylinder supercharged gas engine type MAN E2876 LE302, of displacement Vs =12.82 dm^3, which is designed to drive a generator. The natural gas mixer feeding was the factory configuration. In order to achieve the possibility of new fuel feeding, there was designed and built the special fuel supply system similar to the common rail enabling separation of the gas line and liquid fuel line. To control the size of the gas and liquid fuel doses, ignition timing adjustment, the throttle opening and trim the emergency system, the special programmable motor controller, developed in LabView program, was constructed and applied.

This type of system allows feeding the engine with gas and liquid fuel separately, as well as the practical implementation of dual fuel supply. The controller is equipped with a knock sensor, which has clearly defined the clattering limit for each of the cylinders, in all analyzed operating conditions of the engine. The process of combustion in each cylinder is supervised by a thermocouple placed in the outlet channel of each of the cylinders, directly at the exhaust port of the cylinder head. There were examined and recorded the concentration of: carbon monoxide CO, hydrocarbons THC, nitric oxides NO_x, carbon dioxide CO_2 and oxygen O_2. In addition, the effect of that fuel feeding on other engine parameters such as torque, power, fuel consumption, total efficiency, air excess number **λ** and exhaust gas temperature has been investigated.

Due to the special properties of applied gaseous fuels, against possible leakage of the fuel, the special double-walled pipe system delivering natural gas or hydrogen to the engine was used. Furthermore, the test stand was equipped with a system for cooling and suctioning fumes from above the engine. The laboratory facility sensors identified concentrations of methane and hydrogen.

4. Determination of the engine working parameters

All measurements on the energy performance of engine and toxic exhaust emissions were carried out at a constant engine speed 1500 1/min and different engine load. These conditions correspond to the operation of the engine in the unit generator. Among the tested engine control parameters which have to be adapted to the type of fuel tested were: ignition timing and air excess number **λ**.

Both of these parameters have a significant impact on the process of combustion in the cylinder, resulting in both the value of the parameters of delivered energy and toxic exhaust emissions. The test engine temperature must not exceed 700^{o}C because of the thermal resistance of the turbocharger (turbine), which is important in determining the maximum power of the engine fed with such type of fuel. In addition, both the value of the excess air number **λ**, and especially the value of ignition timing are closely related to the occurred phenomenon of knock. For this reason for each operating point of the engine, the two control parameters were adjusted individually. Simultaneously with measurements of the engine operating parameters, measurements of the concentration of selected components of the exhaust gas were carried out.

It is necessary to evaluate and analyze the combustion process in the engine cylinder. The concentration of oxygen in the engine exhaust also allowed calculating the excess air number **λ**, the values of which are crucial for the combustion of fuel and values of toxic exhaust emissions.

The change of operating parameters of the engine was carried out by quantitative and qualitative regulation and thereby also had an impact on the development of the combustion process and the concentration of individual exhaust gases components. For the practical implementation of the research results associated with the dual fuel fed engine, the strategy differentiating supply of chemical energy flux depending on the current availability of both gaseous fuel and liquid phase fuel was elaborated.

A reflection of this strategy is an example of the imaging method of engine power regulation shown in figure 1 where engine power 100 kW, marked on the graph as H2+MIX, was achieved by hydrogen feeding only. Further increase of the engine power up to 140 kW was obtained by increasing the dose of the liquid phase at constant hydrogen consumption. For the case of H2+MIX the power 130 kW was obtained when only hydrogen was applied. Only above of this power, the engine was additionally fed with a liquid fuel.

In both cases, the liquid phase consisted of a mixture of 50% n-butanol and 50% isobutanol. Fuel is tentatively designated as MIX. In the case of using only the liquid phase, power output was limited to 105 kW. Engine operation using only the liquid phase led to a phenomenon of diffusion of fuel to the lubricating oil. This was mainly caused by the imperfect process of atomization of the liquid phase during the formation of air-fuel mixture. Application of such a dual fuel supply system is generally associated with the necessity of obtaining a compromise between cost of equipment and accessories, and the actual possibilities of use of chemical energy fluxes of the administered fuels. In the case of the strategy used for dual fuel feeding presented in this publication, dosing of the liquid phase made possible once to extend the scope of the load from Ne = 150 kW (supplying pure hydrogen) to Ne = 190 kW (with use of dual fuel feeding). This value of load (for pure hydrogen feeding) was impossible to achieve, because increase the load above 150 kW resulted in the anomalies of combustion process.

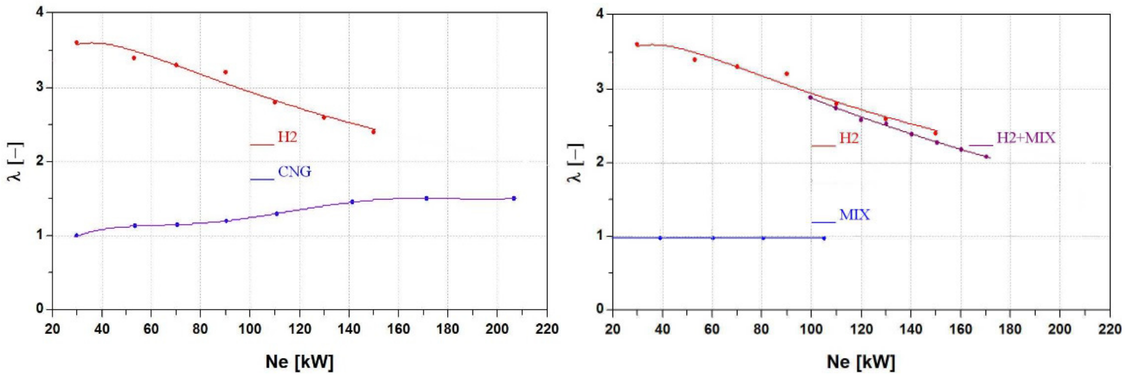

Figure 1. Comparison of air excess number λ, when the engine was fed with mixture of natural gas and hydrogen, and with a mixture of hydrogen and alcohols.

Compared to natural gas feeding, when the engine was fed with hydrogen, the concentration of carbon monoxide and hydrocarbons was negligible and resulted mainly from the combustion of lubricating oil (figure 2).

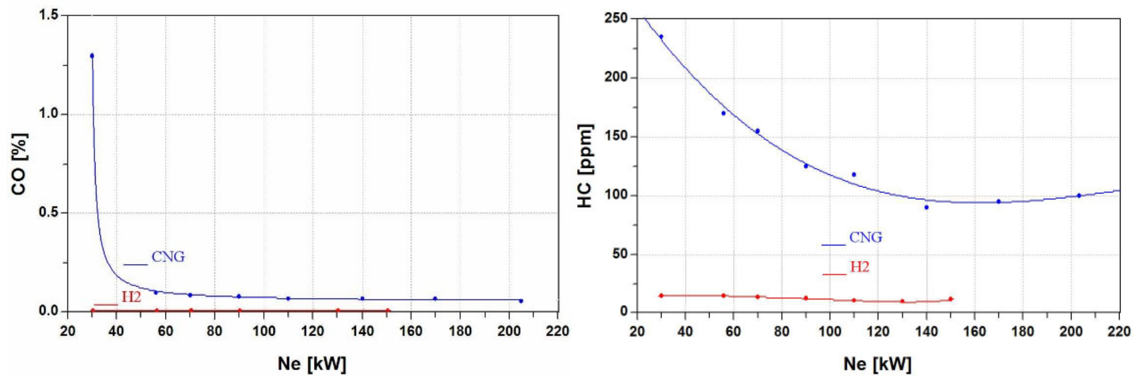

Figure 2. Comparison of the concentration of carbon monoxide and hydrocarbons for MAN engine fuelled with hydrogen or natural gas (n = 1500 1/ min).

During the engine feeding with hydrogen, slight increase in the concentration of nitrogen oxides was observed only for the state of load close to the maximum, and throughout the range of concentrations the value was very small (figure 3).

An important parameter is the engine's total efficiency. The higher value of total efficiency for engine fed with natural gas is obtained mainly due to a smaller share of the mechanical power loss in relation to the effective power. The given constant value of mechanical losses of the engine as well as the lower indicated power achieved by the hydrogen supplied engine result in a smaller value of total efficiency. In both cases, however, the value of total efficiency of the engine is high and during the natural gas feeding achieves the maximum value of approximately 42% and during the hydrogen feeding approximately 37%.

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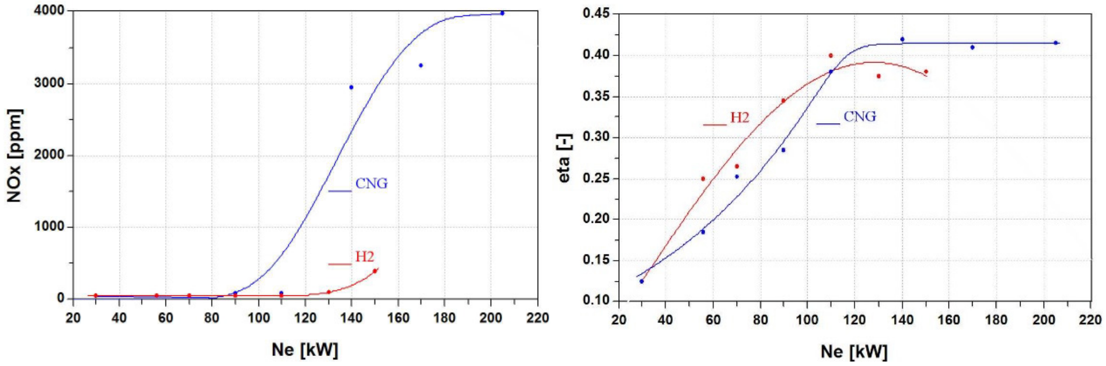

Figure 3. Comparison of the concentration of nitric oxides and total efficiency of MAN engine fuelled with natural gas or hydrogen (n = 1500 1/ min).

5. Conclusions

The study showed that the unconventional waste fuel from the chemical industry can be used to power the internal combustion engines. In this case, obtaining favorable values of operating parameters should be regarded as a success. With sophisticated engine control system in comparison to the typical mixing system, a significant increase in total efficiency has been obtained. It is also possible to use the liquid fraction of the alcohol which requires an appropriate strategy of supply. The proposed control system enables not only application of different liquid and gaseous fuels but also application of the fuels which chemical composition vary within the relatively short time intervals. Besides it is possible to apply the different optimizing procedures thanks to which one can obtain the biggest engine general efficiency and the lowest value of concentration of the individual exhaust gas toxic components.

In the domain of control systems development, the described system is unique, because is based on the generally available engineering tool, which is LabView environment and creates the possibility of individual fitting to every application in which the source of propulsion is combustion engine.

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